CASE FILE
COPY



NACA RM E55L15

NACA

# RESEARCH MEMORANDUM

## DESIGN AND TEST OF MIXED-FLOW IMPELLERS

## VII - EXPERIMENTAL RESULTS FOR PARABOLIC-BLADED IMPELLER WITH ALTERNATE BLADES CUT BACK TO FORM SPLITTER VANES

By Walter M. Osborn

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
March 16, 1956
Declassified January 20, 1958

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

# DESIGN AND TEST OF MIXED-FLOW IMPELLERS

# VII - EXPERIMENTAL RESULTS FOR PARABOLIC-BLADED IMPELLER WITH ALTERNATE BLADES CUT BACK TO FORM SPLITTER VANES

By Walter M. Osborn

3978

T-00

## SUMMARY

In an experimental investigation, a modified parabolic-bladed centrifugal impeller was altered by cutting back every other blade to form splitter vanes. The performance of the splitter-vaned impeller was investigated over a range of equivalent impeller tip speeds from 900 to 1500 feet per second and a range of flow rates from maximum to point of incipient surge. At a speed of 1300 feet per second, the peak pressure ratio and the maximum adiabatic temperature-rise efficiency (based on measurements taken at a radius twice the impeller-outlet radius in a vaneless diffuser) were 3.06 and 0.796, respectively. At the maximum speed of 1500 feet per second, the peak pressure ratio was 4.03 and the maximum efficiency was 0.780. The maximum efficiencies over the speed range tested were between 0.780 and 0.825.

The splitter-vaned impeller, as compared with the fully bladed impeller, had slightly lower peak pressure ratios and maximum efficiencies at all speeds investigated. The loss in maximum efficiency was between 0.015 and 0.035 over the speed range tested. The splitter-vaned impeller had a greater weight-flow operating range than the fully bladed impeller, especially at the higher speeds (95-percent increase at 1500 ft/sec).

## INTRODUCTION

A parabolic-bladed centrifugal impeller (ref. 1) was recently modified by a newly developed design procedure (ref. 2) to eliminate potential flow eddies and reduce the velocity gradients from inlet to outlet along the hub contour. A comparison of the performance characteristics of the original and modified impellers (ref. 3) showed that the modified impeller had better performance characteristics than the original at all speeds tested. The greatest gains in performance occurred at speeds above 1300 feet per second.

It is shown in the solution of the flow through this impeller (ref. 2) that the difference in relative velocity between the pressure and suction faces of the blade is small near the inlet. The difference increases only gradually to a point approximately one-third of the distance through the impeller, from which point the difference rapidly increases until it is tripled in magnitude toward the outlet.

Because of the low velocity difference (or loading) near the inlet, it appeared feasible to cut back alternate blades to the point where the loading began to increase rapidly and to determine the effect upon impeller performance. There are at least two advantages in cutting back the blades: (1) reduction of surface friction, and (2) greater ease in manufacturing, especially for scaled-down versions of the impeller. In cutting back full blades or inserting partial blades to form splitters, losses due to improper angle of flow into them may result. Computations to determine the proper blade-inlet angle were not made, since a method of solution was not apparent. In addition, mixing losses may be incurred by unequal flow distribution in the two passages adjacent to the splitter blade.

3978

The increase in flow area at the inlet was expected to increase the maximum weight flow of the impeller. However, no analysis was made in the hub-to-shroud plane to determine the effect of the greater flow area upon the velocity gradients, which also could cause a change in efficiency.

This report presents the performance characteristics of the modified parabolic-bladed impeller with every other blade cut back to form splitter vanes and compares the performance with that of the fully bladed impeller (ref. 3). The investigations were made at the NACA Lewis laboratory.

## SYMBOLS

$f_s$ slip factor, ratio of absolute tangential velocity at exit to impeller speed at exit, approximated by ratio of measured enthalpy rise to $U^2/gJ$

g acceleration due to gravity, 32.3 $ft/sec^2$

J mechanical equivalent of heat, 778.2 ft-lb/Btu

L ratio of distance along impeller shroud from inlet to total length of shroud

M weight flow through single passage, lb/sec (ref. 5)

3978

CO-1 back

$r$ radial distance, ft (ref. 5)

$U$ actual impeller tip speed, ft/sec

$w$ actual air weight flow, lb/sec

$z$ axial distance from entrance edge of blades, in.

$\delta$ ratio of inlet total pressure to NACA standard sea-level pressure of 29.92 in. Hg abs

$\eta_{ad}$ adiabatic temperature-rise efficiency

$\theta$ ratio of inlet total temperature to NACA standard sea-level temperature of 518.7° R

$\psi$ stream function (ref. 5)

## APPARATUS AND INSTRUMENTATION

The modified parabolic-bladed impeller (ref. 3) having every other blade cut back an axial distance $z$ of 1.5 inches to form a splitter vane was used for this investigation. The leading edges of the splitter vanes were thinned to 3/32 inch and finished with a 1/32-inch radius on the leading edge. A photograph of the impeller is shown in figure 1. The remainder of the apparatus is the same as that described in references 3 and 4.

The outlet measuring station is located at a 12-inch radius (twice the impeller-outlet radius) in the vaneless diffuser. The outlet (diffuser) instrumentation is the same as that described in reference 3. All other instrumentation is the same as that described in reference 4.

## PROCEDURE

This investigation was carried out at a constant inlet-air pressure of 20 inches of mercury absolute. The inlet temperatures varied from ambient to -55° F. (It was necessary to run 900 ft/sec with -50° F inlet-air temperature in order to avoid the drive-motor critical-speed range.) The flow rate was varied from maximum to the point of incipient surge by varying the outlet pressure.

The impeller equivalent speed was varied from 900 to 1500 feet per second based on an impeller-outlet radius of 6 inches. Data for an equivalent speed of 1600 feet per second could not be obtained because of the speed limitation of the rig.

The test and computational procedures are the same as those used in reference 4.

## RESULTS AND DISCUSSION

The over-all performance characteristics for the modified parabolic-bladed impeller with splitter vanes are presented in figure 2 for a range of speed from 900 to 1500 feet per second. The peak pressure ratio and maximum adiabatic efficiency at 1300 feet per second equivalent tip speed (1331 ft/sec theoretical design speed) were 3.06 and 0.796, respectively. At the maximum speed of 1500 feet per second, the peak pressure ratio was 4.03 and the maximum efficiency was 0.780. The maximum efficiencies over the speed range tested were between 0.780 and 0.825, and the average Mach numbers at the outlet (diffuser) measuring station for the maximum-efficiency points were between 0.325 and 0.452 (fig. 2(b)).

3978

Experimental results for the impeller with splitter vanes and the fully bladed impeller are compared in figure 3. The fully bladed impeller had a slightly higher peak total-pressure ratio than the impeller with splitter vanes at all speeds investigated (fig. 3(a)). The loss in pressure ratio of the splitter-vaned impeller as compared with the fully bladed impeller was less than 0.5 percent except at the speeds of 1100 and 1300 feet per second, where the loss was approximately 2.4 percent. The splitter-vaned impeller had slightly lower maximum efficiencies than the fully bladed impeller by 0.015 to 0.035 over the speed range tested (fig. 3(b)). The slip factors at the maximum-efficiency points were slightly higher for the splitter-vaned impeller (fig. 3(c)).

The maximum weight flow for the splitter-vaned impeller is greater than that for the fully bladed impeller (fig. 3(a)) because of the increased flow area available at the inlet of the splitter-vaned impeller (the fully bladed impeller choked in the inlet section). The increase in weight-flow range, especially at the higher speeds (95-percent increase at an equivalent impeller tip speed of 1500 ft/sec) is the main advantage of the splitter-vaned impeller. In addition, it would be easier to fabricate the splitter-vaned impeller, especially on a smaller scale.

Inasmuch as the surge lines for the two impellers are approximately the same (fig. 3(a)), it is probable that the effective angle of attack at the impeller inlet is approximately the same for the two impellers over the speed range tested. There may be an adverse angle of attack at the leading edge of the splitter vanes which results in a lower efficiency for this impeller. While it was impossible to determine experimentally the angle of attack on the splitter vanes, the theoretical results for the 48-inch compressor (ref. 5) may be used to show that the angle of flow in the midpassage is not the same as that of the blades.

Figure 4 shows the flow streamlines for a theoretical solution in the blade-to-blade plane for the 48-inch compressor as determined in reference 5. The solution is for equal weight flow between streamlines.

To show the variation in flow angle across the passage, a splitter vane of the same size and shape (except for length) as the actual blades of the 48-inch compressor has been inserted in the midpassage as shown by the dashed lines in figure 4. The streamline that intersects the leading edge of the splitter vane hits the back side (trailing face) of the splitter vane at a negative angle of attack. Such an angle of attack could explain the lower efficiency of the splitter-vaned impeller as compared with the fully bladed impeller. In addition, figure 4 shows that a larger portion of the weight flow goes to the driving (pressure) side of the splitter vane than to the trailing (suction) side of the splitter vane. Thus, mixing losses at the end of the splitter vane caused by this uneven flow distribution may also contribute to the lower efficiency of the splitter-vaned impeller.

3978

The static-pressure ratios along the shroud of the splitter-vaned and fully bladed impellers are compared in figure 5 for two weight flows at a speed of 1300 feet per second. The static-pressure ratios are higher near the inlet for the splitter-vaned impeller than for the fully bladed impeller because of the increased flow area in the splitter-vaned impeller. At values of L larger than 0.359 (leading edge of splitter vanes), the static-pressure ratios for the splitter-vaned impeller are lower than for the fully bladed impeller. Since the static-pressure ratios should have been approximately the same for the two impellers for these values of L, the results shown in figure 5 support the hypothesis that there probably is an adverse angle of attack at the leading edge of the splitter vanes.

## SUMMARY OF RESULTS

A modified parabolic-bladed centrifugal impeller was altered by cutting back every other blade an axial distance of 1.5 inches to form a splitter-vaned impeller. An investigation of the performance characteristics of this splitter-vaned impeller (based on measurements taken at a radius twice the impeller radius in a vaneless diffuser) produced the following results:

1. The peak pressure ratio and maximum adiabatic efficiency at an equivalent speed of 1300 feet per second were 3.06 and 0.796, respectively. At a maximum speed of 1500 feet per second, the peak pressure ratio was 4.03 and the maximum efficiency was 0.780. The maximum efficiencies over the speed range tested were between 0.780 and 0.825.

2. The splitter-vaned impeller, as compared with the fully bladed impeller, had slightly lower peak pressure ratios and maximum efficiencies at all speeds investigated. The loss in maximum efficiency was between 0.015 and 0.035 over the speed range tested.

3. The increase in weight-flow range, especially at the higher speeds (95-percent increase at an equivalent impeller tip speed of 1500 ft/sec), is the main advantage of the splitter-vaned impeller as compared with the fully bladed impeller.

4. A comparison of the static-pressure ratios along the shrouds of the splitter-vaned and fully bladed impellers shows that losses probably were caused by an adverse angle of attack at the leading edge of the splitter vanes.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 14, 1955

3978

## REFERENCES

1. Anderson, Robert J., Ritter, William K., and Dildine, Dean M.: An Investigation of the Effect of Blade Curvature on Centrifugal-Impeller Performance. NACA TN 1313, 1947.

2. Smith, Kenneth J., and Hamrick, Joseph T.: A Rapid Approximate Method for the Design of the Hub Shroud Profiles of Centrifugal Impellers of Given Blade Shape. NACA TN 3399, 1955.

3. Smith, Kenneth J., and Osborn, Walter M.: Design and Test of Mixed-Flow Impellers. VI - Performance of Parabolic-Bladed Impeller with Shroud Redesigned by Rapid Approximate Method. NACA RM E55F23, 1955.

4. Withee, Joseph R., Jr., and Beede, William L.: Design and Test of Mixed-Flow Impellers. II - Experimental Results, Impeller Model MFI-1A. NACA RM E52E22, 1952.

5. Prian, Vasily D., Kramer, James J., and Wu, Chung-Hua: Theoretical Analysis of Incompressible Flow Through a Radial-Inlet Centrifugal Impeller at Various Weight Flows. I - Solution by a Matrix Method and Comparison with an Approximate Method. NACA TN 3448, 1955.

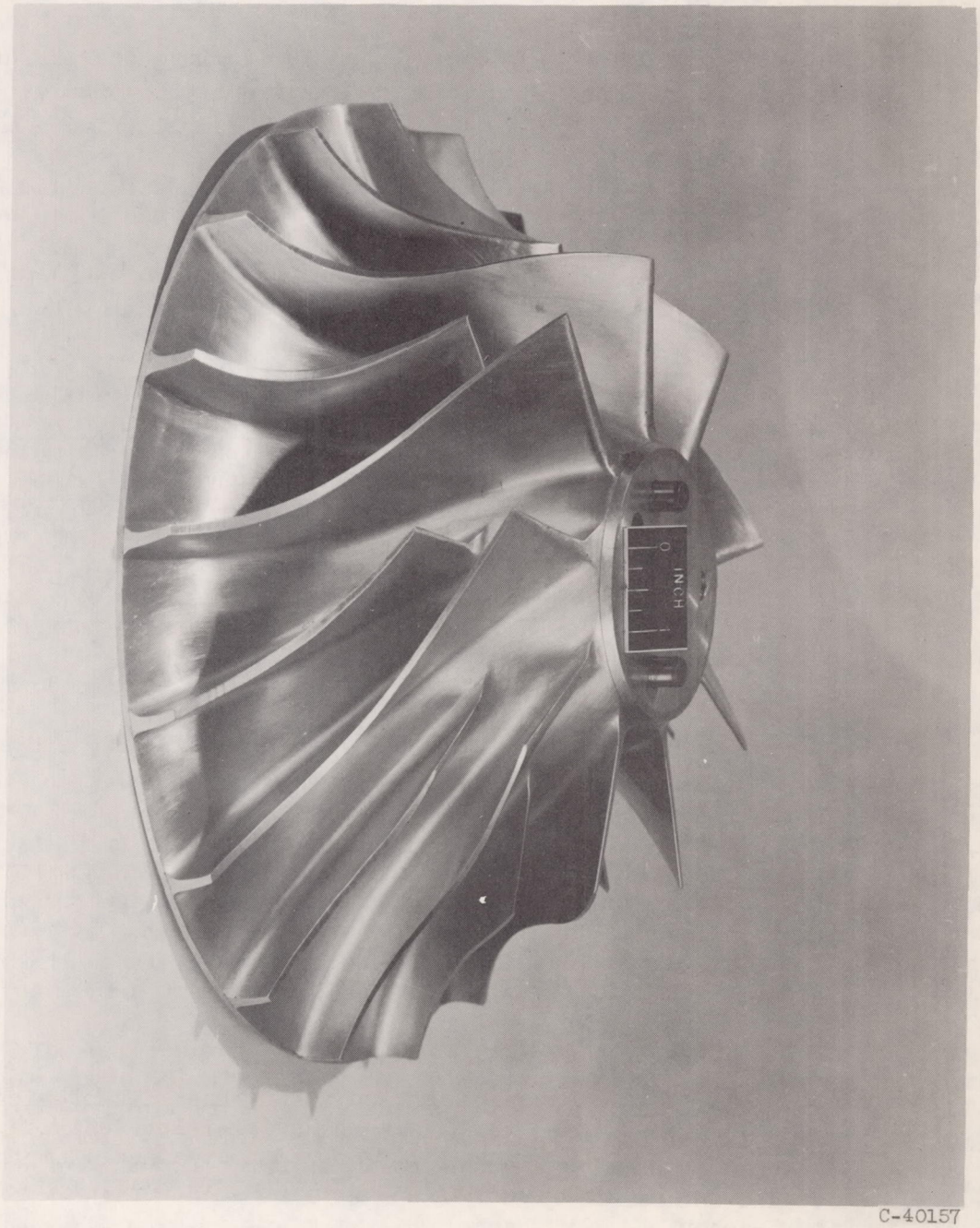
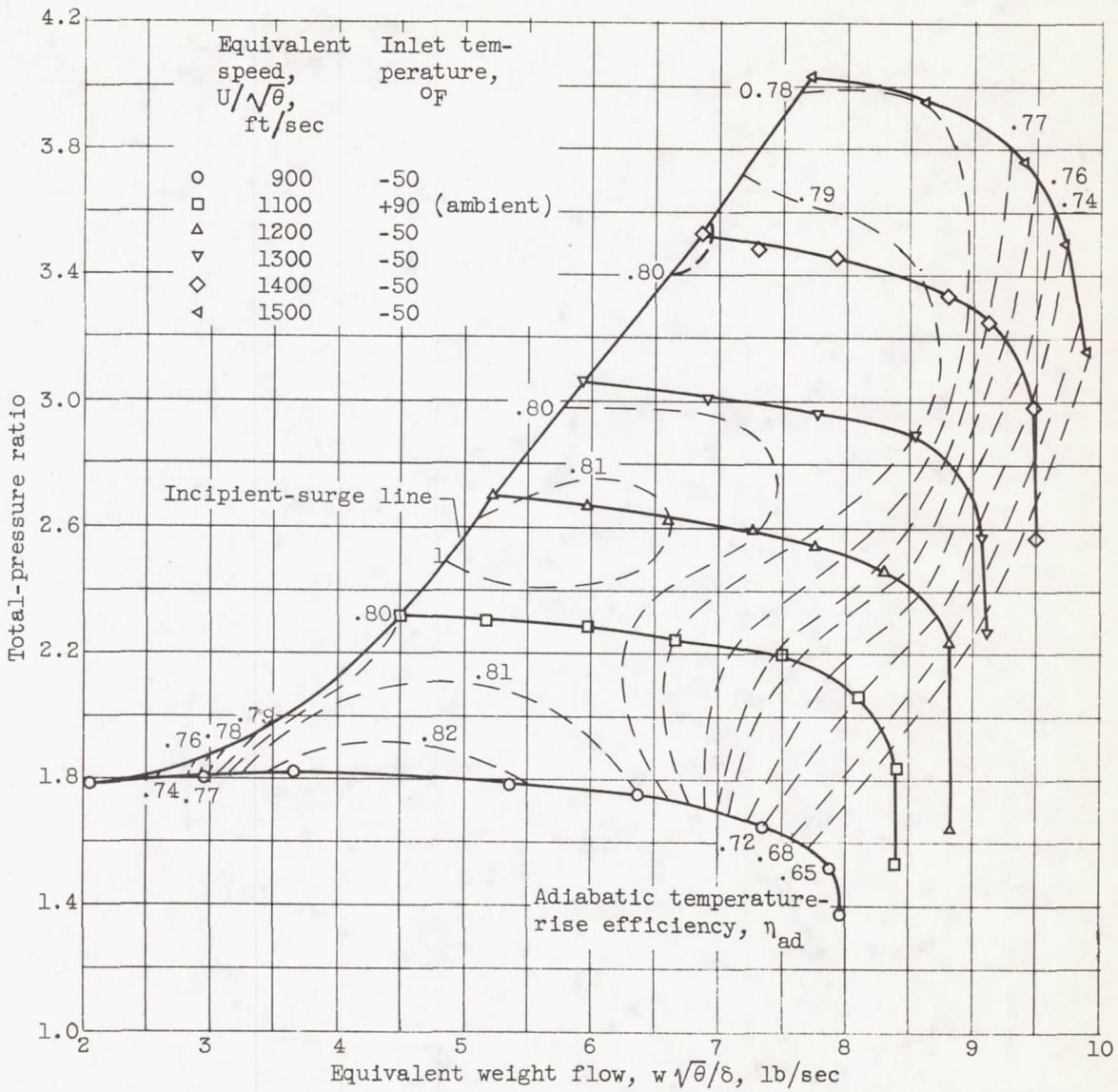


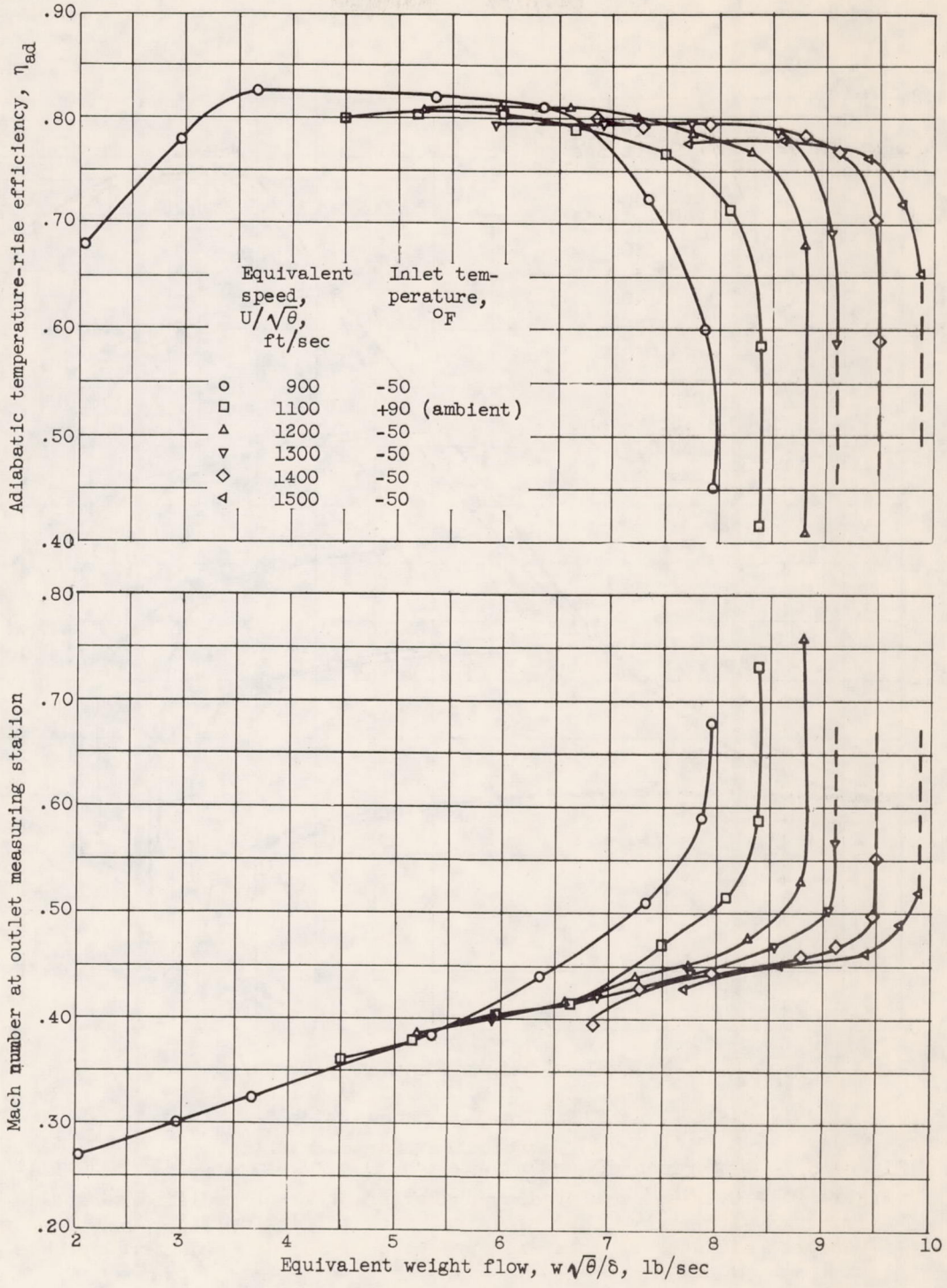

Figure 1. - Photograph of modified parabolic-bladed centrifugal impeller with every other blade cut back to form splitter vanes.




(a) Performance characteristics.

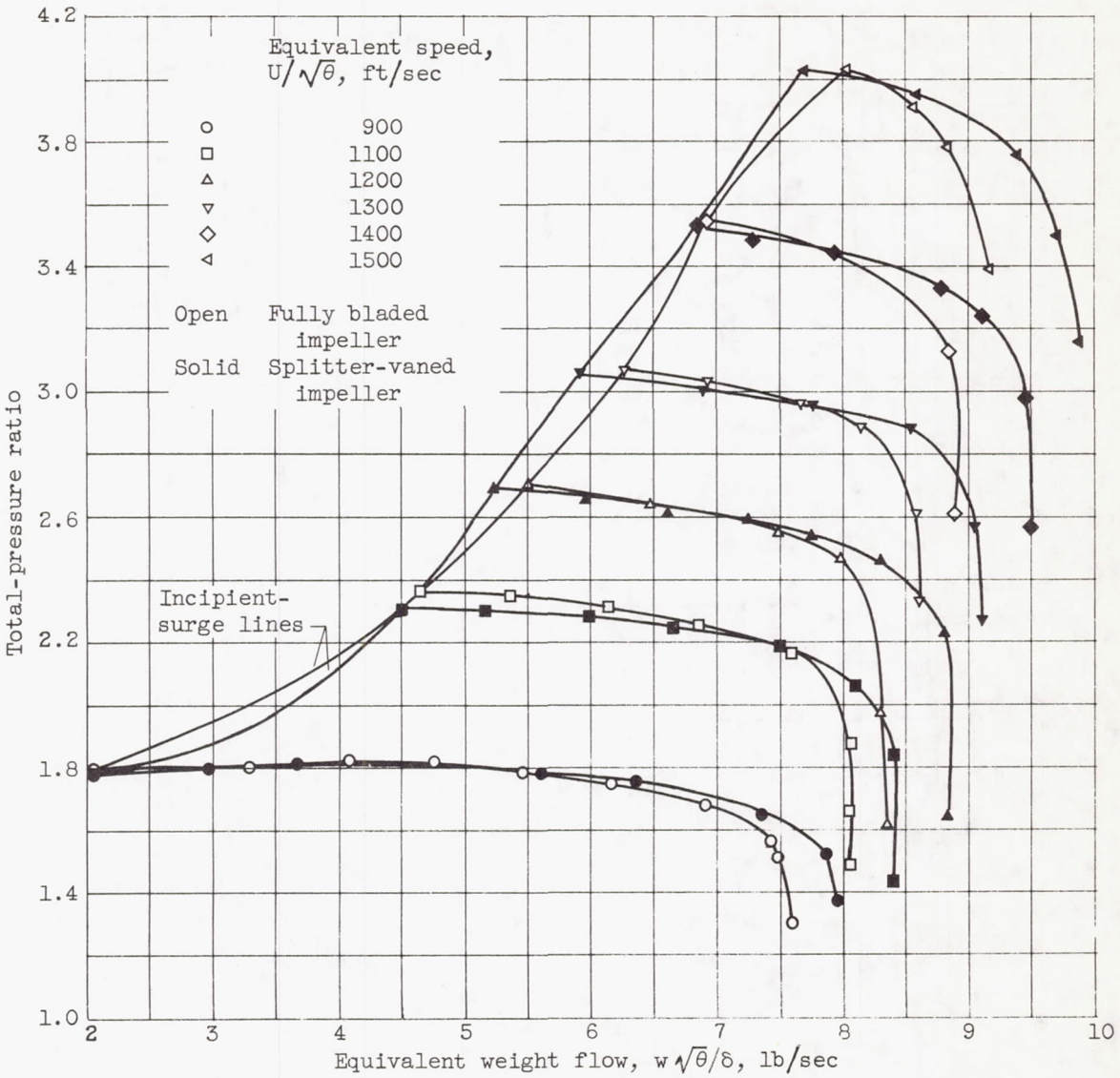
Figure 2. - Over-all performance characteristics of modified parabolic-bladed impeller with every other blade cut back to form splitter vanes and with a vaneless diffuser at inlet-air pressure of 20 inches of mercury absolute.

3978



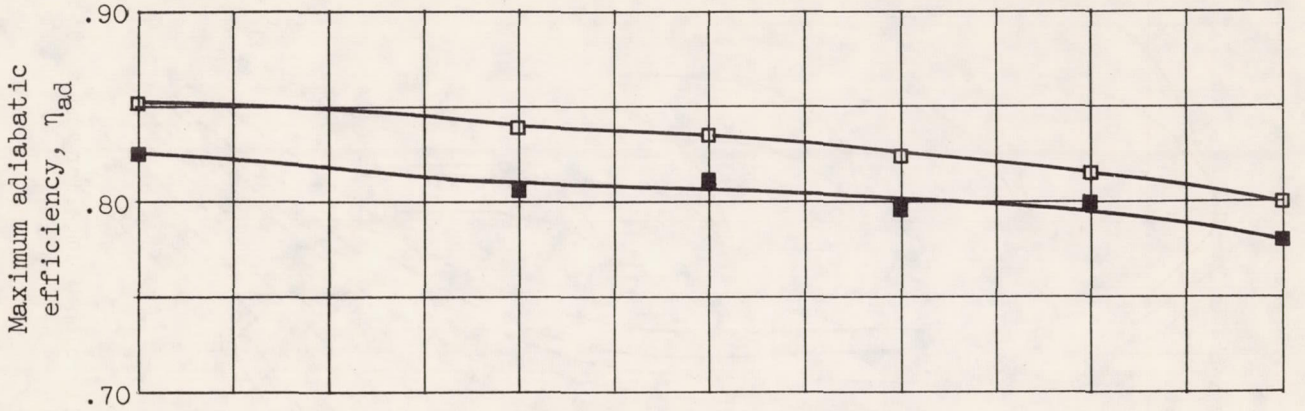

(b) Over-all efficiency and Mach number.

Figure 2. - Concluded. Over-all performance characteristics of modified parabolic-bladed impeller with every other blade cut back to form splitter vanes and with a vaneless diffuser at inlet-air pressure of 20 inches of mercury absolute.

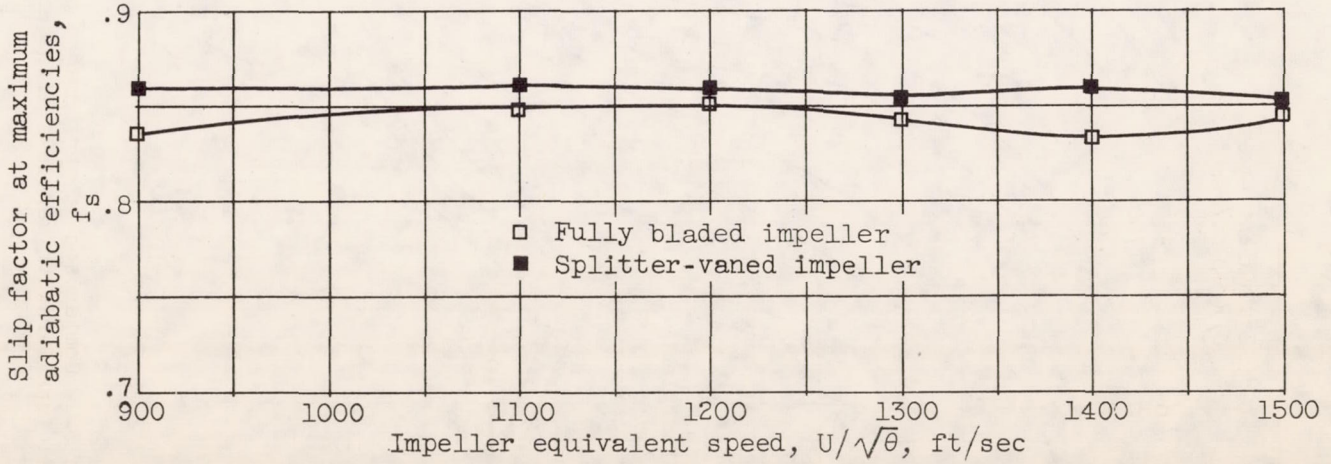



(a) Total-pressure ratio.

Figure 3. - Comparison of performance of fully bladed impeller and splitter-vaned impeller with vaneless diffuser.




(b) Maximum adiabatic efficiency.




(c) Slip factor.

Figure 3. - Concluded. Comparison of performance of fully bladed impeller and splitter-vaned impeller with vaneless diffuser.

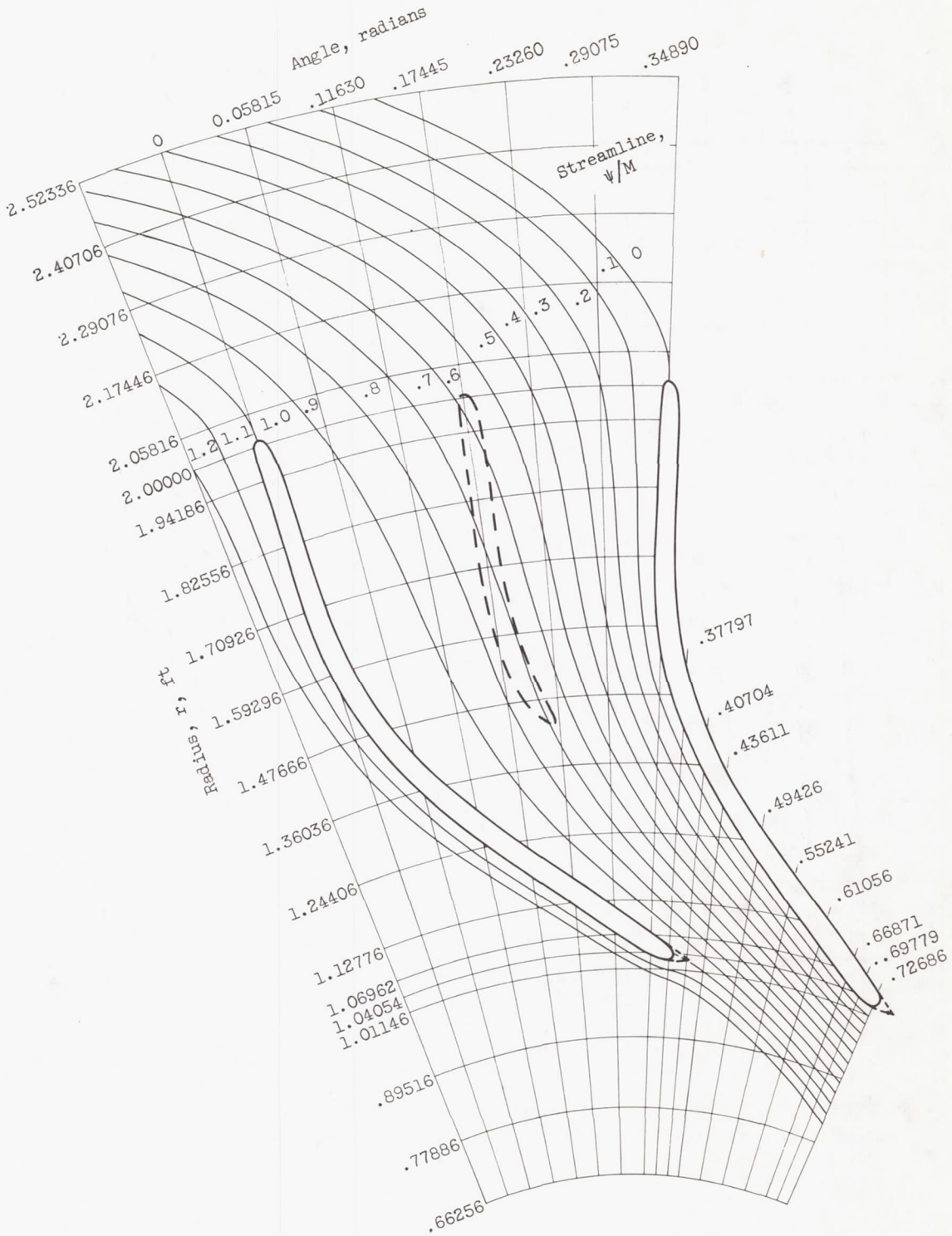



Figure 4. - Theoretical solution for flow between blades of 48-inch centrifugal compressor showing splitter vane positioned in mid-passage (ref. 5). Weight flow, 26.25 pounds per second.

3978

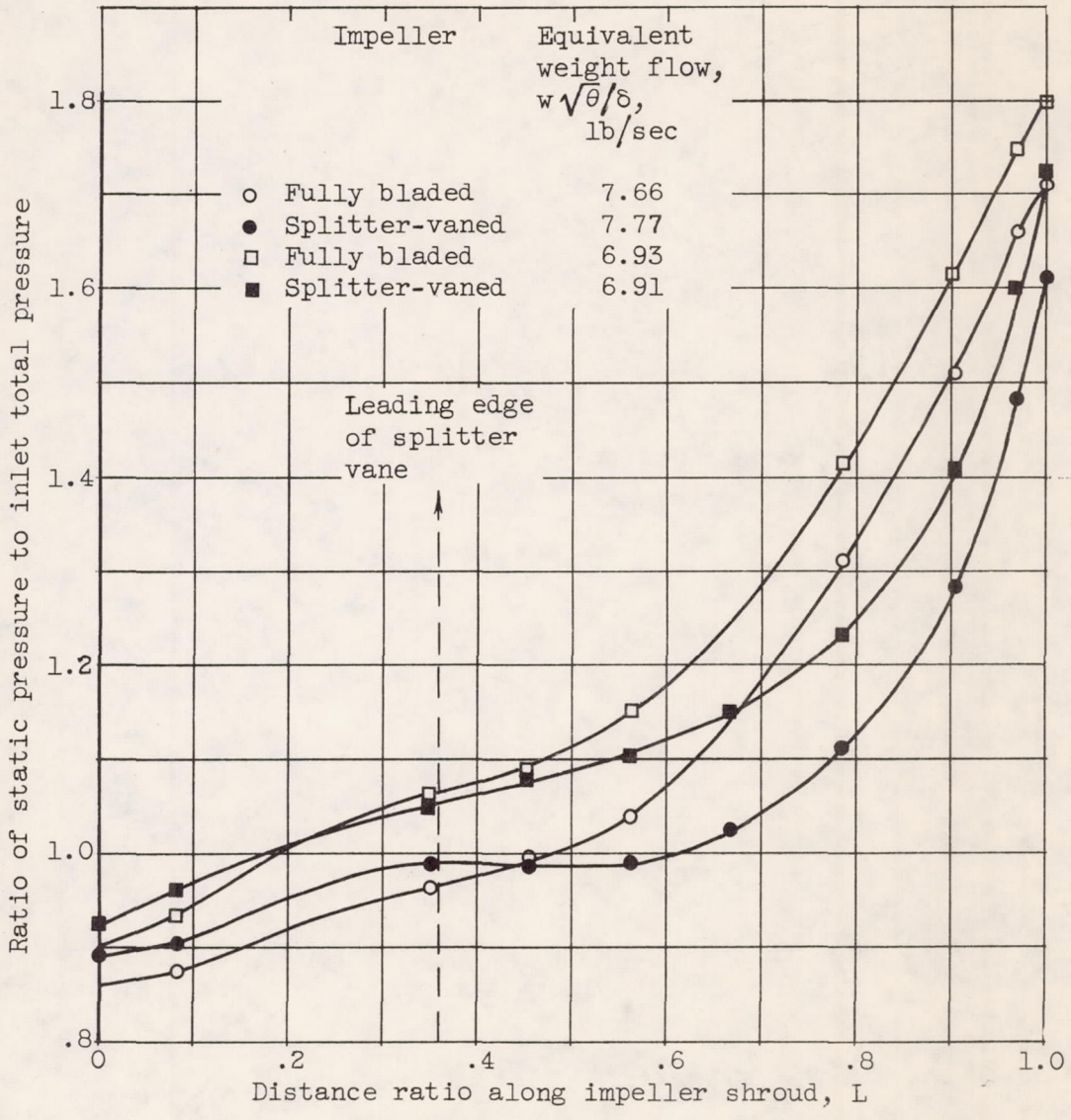



Figure 5. - Comparison of static-pressure ratios along shrouds of splitter-vaned and fully bladed impellers at two weight flows. Equivalent speed, 1300 feet per second.